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TRIP REPORT TO LRL
BERKELEY, CALIFORNIA
January 22 & 23, 1968
and
STRAZA INDUSTRIES AND PATHWAY BELLOWS, INC.
EL CAJON, CALIFORNIA
and
SOLAR DIVISION, INTERNATIONAL HARVESTER COMPANY
SAN DIEGO, CALIFORNIA
January 24, 25, & 26, 1968

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On the San Diego portion of the trip I was accompained by Garry Tidrick of the LRL Mechanical Engineering staff. We were concerned with three general problem areas on the NAL machine design. Two of them had to do with the booster vacuum chamber design. We were investigating the possibility of using a booster vacuum chamber made up as an elliptical convoluted bellows. Also under consideration was the possibility of using a bellows or a smooth elliptical cross section, thinwall metal tube, which had been coated with a ceramic, probably aluminum oxide. This third area of interest was the coating of magnet coil conductors with ceramic as primary electrical insulation.

At LRL I sought to become better aquainted with the people working on the 200 BeV study project and their work and some of the other work underway at LRL. It was not possible to do this in any complete way in the time available. LRL need direction and guidance in working on problems pertinent to the NAL effort, particularly with respect to future work to be carried on there. I recommend that a list of LRL work underway or already completed on major NAL Accelerator systems be prepared and made available to the persons responsible for the major NAL systems. I know that certain of these contacts have been established between the two laboratories, but I have a feeling that NAL has not taken the best possible advantage of the work underway at LRL.

One investigation at LRL that I had not heard about was the idea of utilizing baled automobile scrap as radiation shielding. This is being followed by Vincent Romano at LRL, who has made some contacts on the matter, which we shall pursue. This might well prove to be a way whereby some high grade steel shielding slabs could be obtained at prices approaching that of steel scrap, i.e., of the order of $50.00 a ton for material having a density in the neighborhood of 450 pounds per cubic foot.

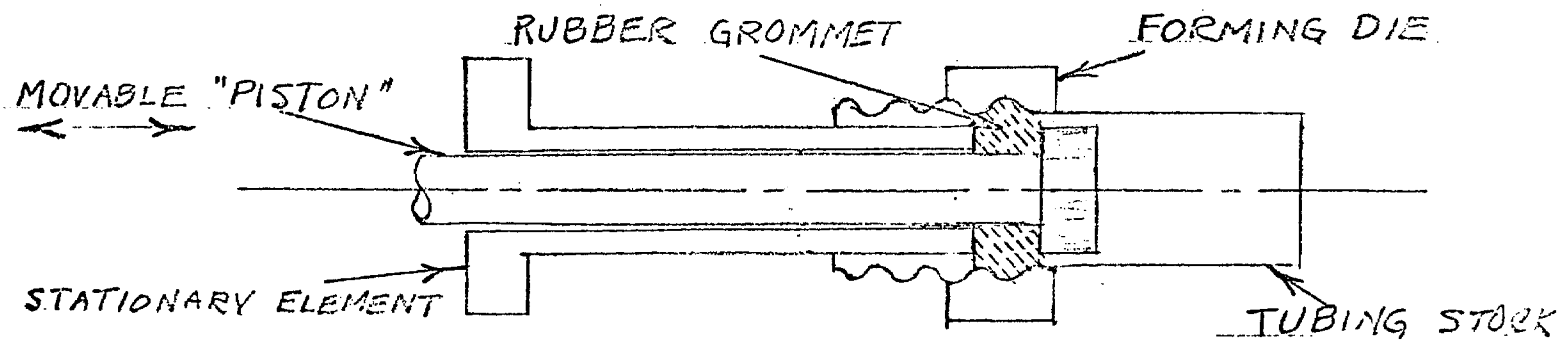
Booster Vacuum Chamber Made From 13 Foot Long Elliptical Cross Section Bellows

While at LRL we talked to a bellows supplier on this subject: Avica Corporation, Newport, Rhode Island, represented by Mr. Howard Mischel.

In the San Diego area we talked to members of and visited the plant of:

1. Straza Industries, 790 Greenfield Drive, El Cajon, California 92021, conferring with Mr. C. John Gibson, Vice President, Marketing, Mr. John Lumm, Ceramic Engineer, and Mr. Frank Urbanak, Production Engineer.
2. Pathway Bellows Incorporated, 1452 North Johnson Street, El Cajon, California, conferring with Mr. William R. Price, President, and Mr. Tom Owen, Vice President, Sales.

All of these people described an all metal bellows forming technique, generally similar to the procedure the Avica people called "Bulge Forming" in which (in the typical case) one bellows convolution is formed at a time; although as many as three convolutions can be done, depending on the size of the bellows. In this arrangement a rubber grommet is caused to deflect outward by compressing it axially between the end of a hollow mandrel, and a movable piston as shown in the sketch below. The mandrel diameter or mandrel outside dimensions are approximately those of the bellows tubing and become the finished bellows bore dimensions. The tubing is forced outward by the rubber grommet into the cavity formed by an external die which (in the typical case) is free to move axially. Typically, in the case of elliptical bellows, the corrugation height can be expected to be greater on the ends of the ellipse at the minor axis with about 10% material wall thickness reduction at the outer crest of the convolution. No change in thickness is predicted elsewhere.



All of the bellows fabricators indicated that obtaining a single tubing length from which a 13 foot long bellows might be made continuously presented a problem and predicted that more than likely one or more peripheral joints would be required to make a 13 foot assembly length. It was pointed out that welded tubing could be used just as well as seamless tubing, that welded tubing was often superior to seamless because of better wall thickness uniformity.

We discussed the possibility of using titanium and titanium allovs as a bellows material. The Avica representatives felt that 5 Al 2.5 Sn is probably the best titanium alloy for bellows fabrication. 6 Al 4 V alloy technology is not yet ready with the necessary level of reliability. It was reported that welding is not the problem with titanium, but that its low elongation and low relative ductivity make it a poor choice. Inconel, slightly lower in ductility than 300 series stainless steels, along with the 300 series stainless steel, is probably the best choice for the convoluted geometry. The

Inconel cost for the material alone is 4 to 5 times the cost of stainless steel, however, the finished cost ratio was estimated to be about 1.05 to 1.10, possibly slightly more than the stainless steel costs. Typically, material thickness of .005 inches is about the minimum the bellows fabricator wants to handle for the purpose, this thickness being minimum from a fabrication standpoint and also from the standpoint of diffusion rates in vacuum serivce. It was pointed out that in this respect Inconel is better than stainless steel.

Should it be necessary to join lengths of tubing together to obtain the 13 foot length of convoluted bellows, shorter lengths can be fusion welded with the weld location selected so that it would occur at a convolution crest, a location not necessarily enjoying a position of minimum stress but rather a position most readily inspected.

It may be well at this point to mention that there is some discrepancy over the metal wall thickness required for a bellows vacuum chamber and also for an unconvoluted elliptical tube. A CERN report states that a wall thickness no greater than .0025 inches is required in order to avoid beam instabilities in the accelerator. LRL has not been able to confirm this with any of the experimental work that they have attempted to date. That question therefore seems to be up in the air at the moment.

We were advised by the Pathway Bellows representatives we met that they had been welding .002 inch stock for reactor service as long as 15 years ago and that they had made elliptical bellows 18 years ago. While we were given quite a dissertation by their representatives on their competence, I have learned from private sources that the Pathway firm does make an excellent product and has an extremely good reputation. They have done work for CERN and also for Harwell.

Finally, Solar Division has a considerable experience in bellows fabrication from very small to extremely large bellows. They have had no experience in making elliptical bellows. They did not see any reason, however, why they could not make them and volunteered to attempt it. With their present equipment their length limitation is about a 27 inch long convoluted length. It would be no problem, however, for them to increase this if they had reason to do so, and appropriate tubing lengths were available. They pointed out that convoluted bellows could be given a ceramic coating should this be desired.

<u>Ceramic Coated Elliptical Booster Vacuum Chamber</u>

Of the firms contacted, only Straza indicated any interest or special competence in this subject area. The samples that we have seen at LRL of this type construction were made by Straza and short lengths of these samples have been brought to Oak Brook, and consist of a flame sprayed coating of aluminum oxide, of whatever thickness is desired, applied to a thin-wall elliptical cross section unconvoluted tube of appropriate metal alloy. This coating has good compressive strength and a high modulus of elasticity. Its porosity is its main detraction and would require that the surface be sealed with some type of inorganic glazing material to make it suitable for our purpose. Moreover it was pointed out by Bob Avery and Garry Tidrick at LRL that failure of the elliptical vacuum tube section under external atmospheric pressure load is in tension, both on the inside of the section at the ends of the minor axis and at the outside of the cross section at the ends of the major axis. Tensile strength is not the forte of these coatings.

The type of sprayed ceramic coating applied by Solar, a porcelain enamel or glass, would not be suitable for application to an unconvoluted elliptical thin wall metal tube since the coatings have a low modulus, perform best at low thickness and therefore may be expected to perform poorly in a structural support situation where they are called upon to withstand an atmosphere of external pressure compared to a thick aluminum oxide coating with its high modulus and high compressive strength.

Ceramic Magnet Coil Conductor Insulation

This problem was discussed with Straza Industries, represented by Mr. C. John Gibson, Vice President; Mr. John Lumm, Ceramic Engineer; and Mr. Frank Urbanak, Production Engineer, and with the Solar Division of International Harvester Company, represented by Mr. Alvin R. Stetson, Chief, Process Research Department.

Since the approach of these two companies is basically different, it would be well in this discussion to separate them.

Straza's approach would be the application of a sprayed aluminum oxide coating. When we objected to the porous nature of the coating and its probable hygroscopic tendencies, requesting that this coating be subsequently fired or fused, we were advised that aluminum oxide begins to sinter at or slightly above 2, 600 F, a temperature at least 700 F over the melting point of copper. The Straza representative suggested that the coils might be oversprayed in their entirety with metal such as aluminum or zinc in order to seal the ceramic coating beneath. Straza also suggested that they might wish to use a metallic molybdenum or a nickel aluminide overspray on the copper itself to improve the aluminum oxide spray coat bonding. Prior to this overspray the surface would be prepared by grit blasting.

We were advised that the sprayed aluminum oxide coating can be repaired in the field. Just how this would be done under the overspray mentioned above is not quite clear to me at this time. Moreover, the multiple spraying seems time consuming and expensive. Although no data is available in quantative form at this time to substantiate my attitude, I feel that the process will prove noncompetitive.

We also discussed other ceramic coating processes with the Straza representatives, including electro-coating which involves the use of a water suspended slurry consisting of 10% pigment and 90% deionized water, a process patented by Ford. We were told that most automobiles are painted this way today. A ceramic paint has been developed by the Pittsburgh Plate Glass Company in cooperation with the Binks people in Chicago, manufacturers of paint spraying equipment. The ceramic paints, consisting of ceramic plus a pigment, might be suitable for our use. Straza will check on the components and its probable suitability. We should be hearing from them on this subject in the latter half of February.

The application of a ceramic coating to magnet coil conductors utilizing materials and techniques employed by the Solar Division seems at this point to be a little more promising and worthy of investigation. Solar ceramic coatings are thinner and more refractory than what they term porcelain enamels as the latter are applied to appliances and housewares. All of the ceramic coatings, including porcelain enamels, are fired somewhere between 900°F and 2000°F.

Differential expansion of any ceramic coating of the type proposed will probably not be a problem. If the coating survives firing, it will in all probability never again see a comparable temperature difference in operation. Because of our requirements and limitations, for example the melting point of copper and also the fusion temperature of brazing alloys under consideration, around 1900°F and around 1450°F respectively, the ceramic selected for our application will be the one having the lowest firing temperature that will withstand irradiation. It is suspected that the radiation stability of the material will be related to its thermo-chemical stability. A lead borosilicate would probably behave poorly under irradiation since it is relatively unstable thermo-chemically.

These coatings are prepared by milling a frit in an aqueous suspension (sometimes with additions of minor amounts of clays) to a viscosity slightly thicker than paint. (Clay is used as a suspending agent, a colloid, useful in maintaining the suspension of a frit throughout the body of the liquid.) This mixture of material is called "slip", of paint-like consistency, which is applied at room temperature with a paint spray gun. After drying, the coated material is placed in an oven and fired at appropriate temperature for the coating material used. The firing operation involves fusion of the applied ceramic material. When this has occurred, the work can be removed from the oven and cooled in the air.

Solar experience indicated that the thinnest coating possible is preferred. Mr. Stetson stated that a coating thickness of .008 inches per side is about as much as he would like to see applied, and stated further that cooling becomes increasingly critical with increasing thickness. Depending upon developments, it may be necessary to put inorganic spacers into the coil assembly to maintain the desired turn to turn and layer to layer spacing. (Thickness of applied coatings is generally determined by the use of an eddy current gage.)

Mr. Stetson believes that Solar could develop a specific ceramic coating for our application. This woul require optimization of composition so that the coefficient of expansion, radiation resistance, and other critical attributes could be matched optimally.

The firing process was discussed briefly. Coils could be fired in a furnace or the coating could be fired progressively from one end of the coil to the other, one area at a time. We also discussed briefly where the insulating coating might be applied and determined that it could be satisfactorily one in a facility to be set up on the Weston site, delivering formed, bare copper coils to it and completing their insulation on the Weston site.

We compared the breakdown voltage of the unirradiated specimen received from Solar with the specimen that had been irradiated at the ANL gamma facility and noted that the irradiated specimen broke down at a lower voltage than the specimen which had not been irradiated. Because of the uncertain background of the two specimens, it is apparent that a controlled test program is indicated in order that differences in thickness, both local and gross, may be evaluated.

Accordingly it was concluded that Solar ought to give us their recommendations which would probably involve the following:

1. Screen out different coating materials to pick out what would appear to be best.
2. Optimize properties, especially expansion properties to best match the expansion of copper. The next most important property is firing temperature. Compatibility of the brazing alloy utilized must also be considered and its melting temperature requirements considered. Bond strength of the coating to copper must be determined both before and after irradiation. Because the coating material can be applied by spraying or by dipping, the application method should be optimized. (Spraying is generally preferable to dipping). And finally the elastic modulus and the breakdown voltage of the coating should be determined both before and after irradiation.
3. The suitability of the selected coating for field repair should be evaluated and field repair techniques examined.
4. At this point the development of an application technique to a small prototype cross section is indicated.
5. Insulate a magnet coil model.

While the steps enumerated above generally describe the sort of thing Solar will consider, their "project suggestion" will also contain an estimate of cost, manpower and schedule plus a statement of definite objectives to be attained.

Several additional coating samples were given to us for preliminary radiation screening. Mr. Stetson estimated that the first phase of the program might involve as much as six months and would require the very best kind of cooperation from NAL in the irradiation of specimens.

Flanges, Welded and Quick-Open

Considerable work has been done at LRL on both welding flanges and quick-open designs. Some of this work has been done in connection with the 200 BeV study group and a considerable amount of work has been done by the OMNITRON group, specifically Dick Wolgast and Norm Milleron. In addition, the Solar Division has developed a combination weld-quick-opening flange. We were told that North Amercian Aviation, probably the Los Angeles Division, has developed an orbital welding device for joining flanges in ducting. I will investigate the report on North American Aviation and report on it separately if it seems worthwhile.